Improving Surface Flux Parameterizations in the Navy's Coastal Ocean Atmosphere Prediction System

Shouping Wang
Naval Research Laboratory
Monterey, CA 93943
Phone: (831) 656-4719 Fax: (831) 656-4769 email: wang@nrlmry.navy.mil

Qing Wang
Meteorology Department, Naval Postgraduate School
Monterey, CA 93943
Phone: (831) 656-7716 Fax: (831) 656-3061 email: qwang@nps.navy.mil

Award Number: N0001406WX20664

LONG-TERM GOAL

The long-term goal is to understand the physical processes that critically regulate the coupling between the oceanic and atmospheric boundary layers and develop advanced parameterizations of this interaction for a new generation of coupled ocean-atmosphere models.

OBJECTIVES

The objective of this research is to improve the surface flux and boundary layer turbulence parameterization in COAMPS®[1] for low- and high-wind events over the ocean in the context of air-sea interaction. Special emphasis will be placed on flux parameterizations in low-wind regimes in collaboration with the Coupled Boundary Layer/Air-Sea Transfer (CBLAST) Defense Research Initiative community.

APPROACH

There are two complementary and strongly interacted components in our study: modeling and observational efforts. Our first approach is to use COAMPS as a tool in understanding the physical processes and developing new parameterizations for the surface and boundary layer turbulence mixing. We provide real-time COAMPS weather forecasts for each intensive observational period of the CBLAST-Low field experiments, and therefore establish a focused model dataset, which can be used, with the measurements, to evaluate the model physics and investigate the impacts of the interaction on the mesoscale weather prediction. We also use various single column versions of COAMPS and experiment data to study the detailed turbulence processes, and develop new parameterizations. The second approach is the observational study that included measurements in the boundary layer and upper air at the CBLAST Nantucket site. These measurements are critical in the evaluation of the COAMPS forecast and development of the new parameterizations. They also provide a valuable data source for the process study of the air-sea interaction in that area.

[1]COAMPS® is a registered trademark of the Naval Research Laboratory.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
30 SEP 2006

2. REPORT TYPE

3. DATES COVERED
00-00-2006 to 00-00-2006

4. TITLE AND SUBTITLE
Improving Surface Flux Parameterizations in the Navy's Coastal Ocean Atmosphere Prediction System

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory,7 Grace Hopper Avenue,Monterey,CA,93943-5502

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

1. *Continued study of the impact of sea surface temperature (SST) variability on atmospheric boundary layer flow*

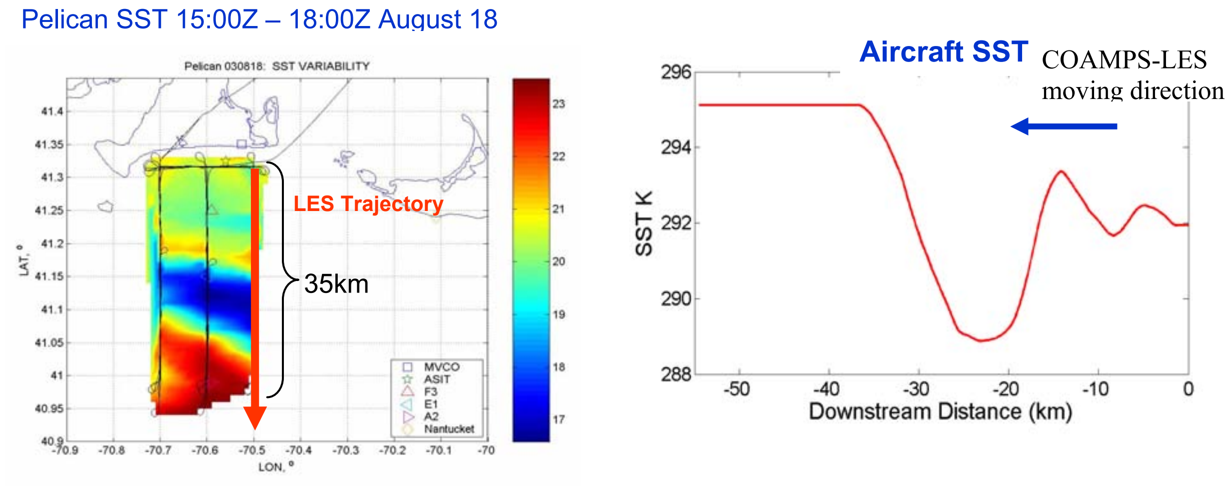

Figure 1. Left: Aircraft observations showed strong SST variability in the area 15 km to the south of Martha's Vineyard Island on August 18 2003. The wind was coming from the northeast. Right: SST derived from the observation and used in the COAMPS-LES Lagrangian simulation.

Aircraft observations in the CBLAST-Low field experiment in August 2003 demonstrated significant small-scale SST variability (6^{o}C over 10km) and corresponding variability of air temperature and winds, as shown in Figure 1 (left). In FY 2004-2005, we used COAMPS simulations to study the overall response of the boundary layer flow to the SST change. In this year, our work has been focused on the physical mechanism that produces the responses. Our first approach is to perform detailed momentum budget study for the high-resolution simulations, which evaluate the contributions from the pressure gradient and turbulent mixing processes. The second approach is to simulate the boundary layer structure using COAMPS-LES and evaluate both momentum and turbulence budgets. By this approach, we investigate the detailed turbulence response to the abrupt SST change. The COAMPS-LES is performed following a semi-Lagrangian trajectory along one of the aircraft leg as shown in Figure 1 (right).

2. *Observational study of transformation of BL structure due to sea breeze onset*

On the measurement side, we have performed detailed analyses on the variation of mean and turbulence statistics using measurements from the CBLAST Nantucket site on a unique case when the sea breeze front passes over the site. The wind direction abruptly changes from the north to the west in less than 1.5 minutes. The question we address is how does the turbulence respond to this abrupt change in the wind direction. We analyzed the temporal change of mean variables of temperature, moisture and CO2. We also calculated turbulent fluxes of temperature, moisture, and momentum using *in situ* measurements at the CBLAST-Nantucket surface observation site.

3. *Evaluation of the new drag coefficient and dissipative heating parameterization for hurricane forecast*

A new drag coefficient (Donelan et al, 2004) and dissipative heating parameterization were implemented in COAMPS in FY 2005. We have continued to evaluate the performance of this development in this year. A total of 18 simulations of 10 tropical cyclones are performed and evaluated.

RESULTS

1. *Continued study of the impact of sea surface temperature (SST) variability on atmospheric boundary layer flow*

When air flows over the sharp gradient of SST shown in Figure 1, the stability at the surface significantly increases, weakening the turbulent mixing near the surface. Consequently, the downward momentum flux is reduced. On the other hand, the decrease of SST tends to increase the sea level pressure due to the atmospheric hydrostatic requirement, which intensifies the pressure gradient in a direction that would also lower the wind speed. Our momentum budget analyses of the COAMPS simulation show that the turbulence mixing contributes significantly to the change of the wind speed and is a dominate term in the budget. The pressure gradient term plays a considerably smaller role in the wind speed change. This is because the spatial scale of the SST change is not large enough to introduce large adjustments in the hydrostatic pressure, while the turbulent structure in the BL immediately responds to the surface stability change.

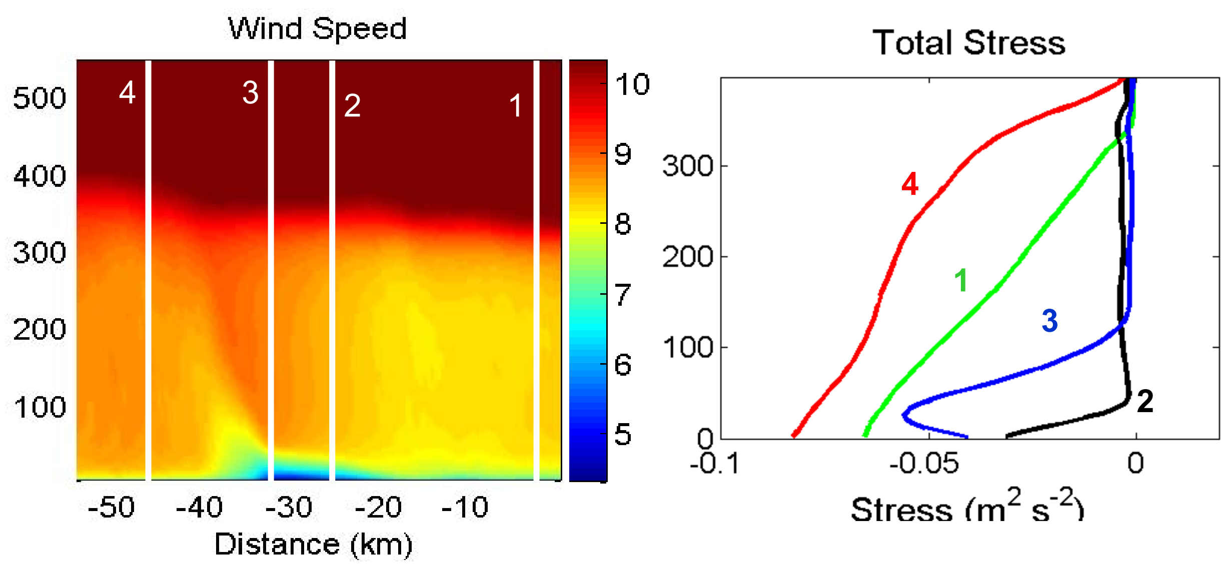

Figure 2. COAMPS-LES Lagrangian simulation of BL flow over SST change. (a): mean wind speed.; (b): momentum flux profiles corresponding to the locations indicated by numbered lines in (a).

We studied the turbulent structure resolved from the COAMPS-LES simulation to understand how the turbulence mixing lowers the wind speed. Figure 2a shows that the surface averaged BL wind speed decreases over the cold SST pool, which is consistent with the COAMPS mesoscale simulation. Figure 2b shows the responses of the turbulent momentum flux to the SST change. In the upwind location (denoted by 1) where the surface layer is weakly unstable, the momentum flux linearly decreases from the surface to the top of the BL layer. The slope of the flux determines the total effect of the turbulence on the wind speed. When the air moves over the cold SST area, the surface stress is reduced by half due to the enhanced stability. An internal boundary layer is developed with a height of only 40 m, compared to the boundary layer thickness of 300 m at location 1. Consequently, the gradient in profile 2 is significantly larger than that of the profile 1. It is this strengthening of the flux gradient that significantly slows the wind speed shown in Figure 2a. It is also the shallowness of the internal boundary layer in profile 2 that is responsible for the strengthening of the gradient. This conclusion is in contrast with the traditional view that the reduced downward mixing slows down the wind speed; and it is consistent with the recent paper by Samelson et al. (2006).

Furthermore, the downward mixing also contributes to the increase of the wind speed when the air moves from the cold to the warm SST region as indicated by profile 3. When the flow is in equilibrium with the surface SST, the entrainment momentum flux makes only a limited contribution (line 4)

2. *Observational study of transformation of BL structure due to sea breeze onset*

As a result of abrupt wind direction changes, the near-surface temperature, specific humidity, and CO_2 concentration changes from the previous over-land air to marine air properties in less than 1.5 minutes. However, it is found that the turbulence field responds to the change over a much longer time scale, about 32 minutes.

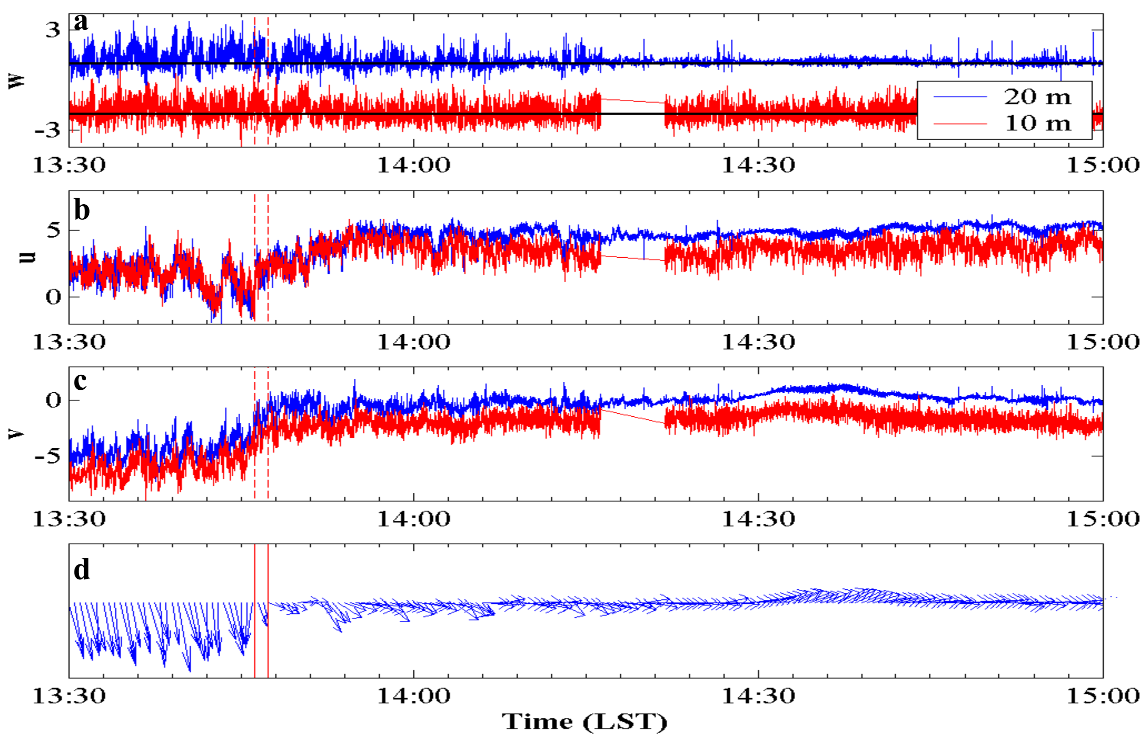

Figure 3. Responses of near-surface variables to the wind direction. a: vertical velocity; b: u component; c: v component; and d: wind direction.

Further analyses of the turbulent spectra also reveals the development of the internal boundary layer (IBL) after the sea breeze front (SBF) passage that contributes to the different behavior of turbulence adjustment at 10 and 20 m. The 20 m level was likely in the interfacial layer between the newly developed IBL and the marine air above, while the 10 m level was within the IBL in equilibrium with the local surface. The results from this study have significant implications on surface flux parameterization in low wind conditions when frequent wind direction changes occur. Because the turbulence transport and the mean quantities adjust to abrupt changes on different time scales, more consideration should be given to parameterizations when the surface fluxes are parameterized in terms of the mean quantities.

3. *Evaluation of the new drag coefficient and dissipative heating parameterization for hurricane forecast*

In general, the results are very encouraging with clear improvement in the hurricane intensity forecast. As shown in Figure 4, the reduction in the average wind forecast errors is about 2 kts at hour 12 after the model goes through the spin-up period, since all simulations presented are cold start runs. This reduction in forecast error increases with simulation duration and reaches 5 kts at hour 30, about 20% reduction in the wind forecast errors. For the TC track forecasts, including the dissipative heating has little impact on the average track forecast at this resolution (not shown here).

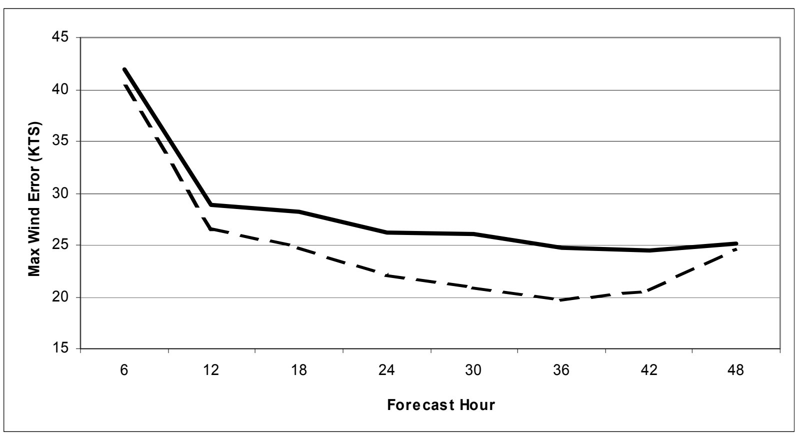

Fig. 4. Mean absolute errors of COAMPS forecast for surface maximum winds (kts) in domain 2 (15-km) of 10 TCs (18 simulations). The solid are for the control simulations without the dissipative heating and the dashed curves are for the simulations with the dissipative heating.

IMPACT/APPLICATIONS

The study of the impact of SST variability on the surface wind provides better understanding of the air-sea interaction. The observational study of the transformation of boundary layer structure due to sea breeze onset suggests that the parameterization of turbulent fluxes should include the impact of the horizontal advection of these quantities. The implementation of the new drag coefficient and dissipative heating scheme results in an improvement of COAMPS hurricane intensity forecasts.

TRANSITIONS

The new transition will focus on the scalar transfer coefficient.

RELATED PROJECTS

Related projects are the ONR-funded project "Numerical Techniques and Cloud-Scale Processes for High-Resolution Models" and the ONR-funded project at NPS "COAMPS Surface Flux and Boundary Layer Parameterization Study Evaluation using Aircraft Measurements".

REFERENCES

Samelson, R.M., E.D. Skyllingstad, D.B. Chelton, S. K. Esbensen, L. W. O'Neil, and N. Thum, 2006: On the coupling of wind stress and sea surface temperature. *J. Climate*, 19, 1557-1566.

Donelan, M.A., B.K. Haus, N. Reul, W.J. Plant, M. Stiassnie, H.C. Graber, 2004: On the limiting aerodynamic roughness of the ocean in very strong winds. *Geophy. Res. Lett, 31*, L18306,doi:10.1029/2004GL019460

CONFERENCE PRESENTATIONS

Wang, S., Q. Wang, J. Cummings, 2006: A Case Study of Impact of Sea Surface Temperature Variability on Boundary Layer Wind Structure. 27th Conference on Hurricanes and Tropical Meteorology,24-28 April 2006, Monterey, CA.

Wang, Q., C. Helmis, G. Katsouvas, 2006: Rapid transition of boiundary layer structure observed on coastal sites. 27th Conference on Hurricanes and Tropical Meteorology,24-28 April 2006, Monterey, CA.